Indicator: Atmospheric Concentrations of Greenhouse Gases (349)

The Earth's temperature depends mainly on the amount of sunlight received, the portion reflected back into space, and the extent to which the atmosphere retains heat. Natural forces (volcanoes, changes in the Earth's orbit, etc.) and human activities (emissions of so-called "greenhouse gases", land use change) affect the amount of energy available to the Earth-atmosphere system and, thus, the Earth's temperature, climate, and weather. Human activities have altered the chemical composition of the atmosphere by the emissions and accumulation in the atmosphere of gases that change how much energy is reflected or escapes back into space, and hence, the Earth's climate. Some of the primary gases that retain heat in the atmosphere are water vapor, carbon dioxide, methane, nitrous oxides, and certain manufactured gases such as chlorofluorocarbons, hydrofluorocarbons, sulfur hexafluoride, and others. Many of these synthetic gases are extremely long-lived, remaining in the atmospheric for hundreds or even thousands of years.

This indicator shows the accumulation of these gases in the atmosphere, as increasing concentrations. Recent data are from networks that monitor the concentrations of these gases in the atmosphere. Historical data result from gas measurements made on air trapped in ice cores at the time the ice was formed. Water vapor is not included as a greenhouse gas, because its concentration is not thought to be directly influenced by water vapor emissions from human activities.

What the Data Show *(Note: These figures will be updated with the latest concentration data available, late in 2005.)*

The concentration of CO2 has varied considerably over geological time (Figure 349-1). From at least 900 A.D. to 1800 A.D., CO2 concentrations stayed relatively constant at about 270 – 290 ppm. Over the past 150 years, CO_2 concentrations have increased by 31 percent to present, and by about 18 percent since 1958.

Methane (CH4) concentrations also remained fairly constant from at least 1000 A.D. until about 1730 A.D. (Figure 349-2). CH4 concentrations then rose from about from about 680 ppm to about 774 ppm in 1850, and then rose more rapidly to over 1700 ppm today. Stated another way, essentially no increase occurred from 1000 A.D. to 1730 A.D. It then took approximately 175 years (c.1905) to add 200 ppm to atmospheric CH4 concentrations, 40 years (c.1945) to add the next 200 ppm, 20 years to add the next 200 ppm (c 1965), and 10 years (c 1975) to add the next 200 ppm. The rates of methane increase began to slow by the late 1970s and then to decline, with less than 200 ppm added to atmospheric concentrations between 1978 and the present. Overall, methane concentrations more than doubled in the past 150 years, although rates of increase have slowed almost to zero in recent years.

Nitrous oxides (N2O) concentrations increased slowly from a thousand years ago until around 1800, when concentrations began to rise more rapidly (Figure 349-3), with large interannual variability. After 1800 N_2O concentrations increased by 15 percent (about 0.25%/year +/- 0.05%/year) to concentrations of 314 ppm in 1998 (IPCC 2001). Recent interannual variations in N_2O concentrations may be explained by changes in use of nitrogen-based fertilizer, biogenic soil emissions, or stratospheric losses due to volcanic-induced circulation changes, but significant uncertainty remains about the drivers of trends and variability of N2O.

The concentrations of some of the manufactured gases peaked around 1994 and now are decreasing (CFC-11, CFC-113, CH_3CCl_3 and CCl_4), while others are increasing more slowly (CFC-12), as a result of emissions reductions under the Montreal Protocol and its Amendments (Figure 349-4). Greenhouse halocarbons not controlled by the Protocol (because they do not contribute to stratospheric ozone losses) continue to increase. For example, the concentration of HFC-23 has increased by more than a factor of three between 1978 and 1995.

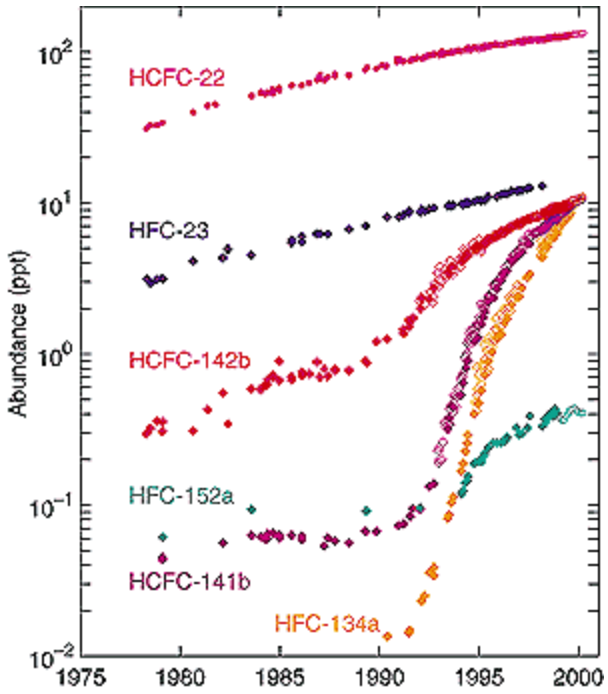


Figure 349-4: *HFC-23 (blue, UEA scale), -152a (green, UEA scale), -134a (orange, NOAA scale), and HCFC-22 (magenta, SIO scale), -142b (red, NOAA scale), and -141b (purple, NOAA scale) abundances (ppt) at Cape Grim, Tasmania for the period 1978 to 1999. Different symbols are data from different measurement networks: SIO (filled circles), NOAA-CMDL (open diamonds, Montzka et al., 1994, 1996a,b, 1999), UEA (filled diamonds, Oram et al., 1995, 1996, 1998, 1999) and AGAGE (open circles, only for 1998 to 2000, all gases but HFC-23, Miller et al., 1998; Sturrock et al., 1999; Prinn et al., 2000). Southern Hemisphere values (Cape Grim) are slightly lower than global averages. Source: IPCC Third Assessment Report: The Scientific Basis (2001)*

Indicator Limitations

- Ozone (O_3) is an important greenhouse gas present in both the stratosphere and troposphere. Trends in atmospheric concentrations of these are discussed in sections ___ and ___ of this report. Unlike the other gases in this indicator, ozone has a very short atmospheric life and is not well-mixed globally; large inter-temporal and geographical variability occurs. The effectiveness of ozone as a greenhouse gas is very dependent on the altitude of the concentrations, with the greatest radiative forcing occurring for concentrations at about 7 kilometers up. Depletion of stratospheric ozone tends to cool the Earth, partially offsetting elevated levels in the troposphere. Confidence in the measurement of ozone and of its contributions to climate change is much lower than for the long-lived greenhouse gases, such as carbon dioxide.

- Ice- core measurements are not taken in real time, which introduces some error into the date of the sample. Where snow accumulation is high, as in the air enclosed in the three ice cores from Law Dome, Antarctica, diffusion of the air is very limited, and allows the samples unparalleled age resolution. Etheridge et al. (1996) reported the uncertainty of the Law Dome ice core CH_4 concentrations to be about 10 ppb, while the precision of analysis of the Law Dome ice core air samples for CO2 was 0.2 ppm (http://cdiac.esd.ornl.gov/trends/co2/lawdome.html). For the Vostok ice cores, Barnola et al. (1991) reported that the age difference between air and ice may be ~6000 years during the coldest periods instead of ~4000 years, as previously assumed – small relative to the ages ranging into the hundreds of thousands of years. Dating accuracy for the ice

cores ranged up to ± 20 years (often less), depending on the method used and the time period of the sample. For CH4 from the Greenland ice sheets, the difference in air content and the ice age ranges from about 8 years for ice at small depths up to 200 years for deep ice. Comparisons across ice cores generally show good agreement, suggesting that the measurement errors are insignificant. (See, for example, http://cdiac.esd.ornl.gov/trends/co2/vostok.htm) More information on the accuracy of measurements of ice samples and other measurement methods can be found at: http://cdiac.esd.ornl.gov/by_new/bysubjec.html#atmospheric

Data Sources

All data sets can be accessed through: Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. at: http://cdiac.esd.ornl.gov/trends/trends.htm

References

Barnola, J.-M., D. Raynaud, A. Neftel, and H. Oeschger. 1983. Comparison of CO2 measurements by two laboratories on air from bubbles in polar ice. Nature 303:410-13.

Etheridge, D.M., L.P. Steele, R.L. Langenfelds, R.J. Francey, J.-M. Barnola, and V.I. Morgan. 1996. Natural and anthropogenic changes in atmospheric CO2 over the last 1000 years from air in Antarctic ice and firn. Journal of Geophysical Research 101:4115-4128.

Intergovernmental Panel on Climate Change (IPCC). 2001. Report of the Science Working Group.

National Research Council of the NAS. 2004. Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, Prepublication version, Dec.16, 2006.

Summaries of methods and discussions of data sets of atmospheric concentrations of greenhouse gases can be found in: Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. at: http://cdiac.esd.ornl.gov/trends/trends.htm

Graphics

Figure 349-1. CO2

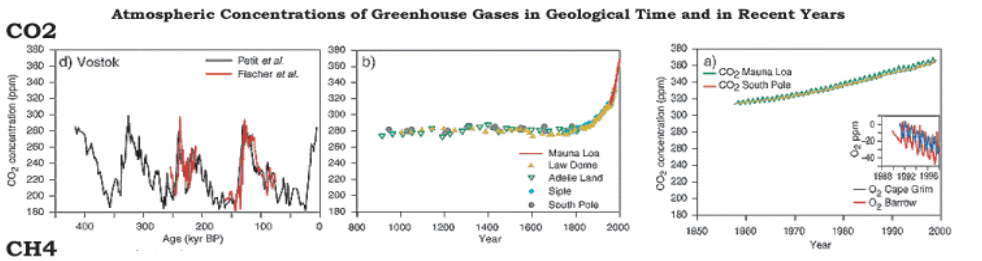


Figure 349-2. CH4

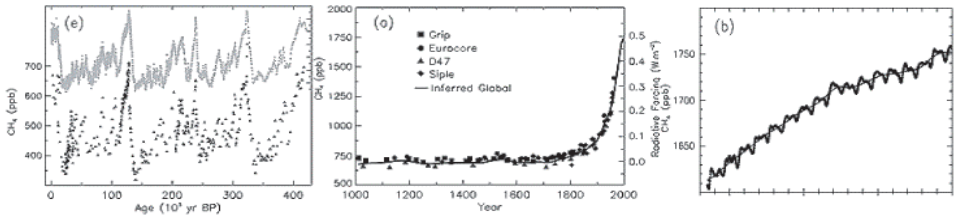
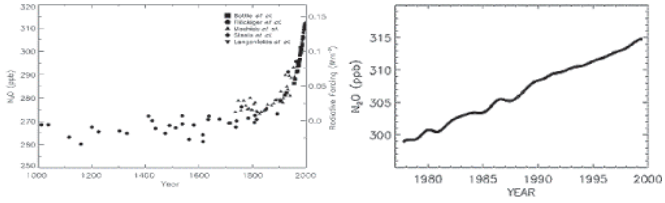


Figure 349-3. N2O



R.O.E. Indicator QA/QC

Data Set Name: ATMOSPHERIC CONCENTRATIONS OF GREENHOUSE GASES
Indicator Number: 349 (114470)
Data Set Source:
Data Collection Date:
Data Collection Frequency:
Data Set Description: Atmospheric Concentrations of Greenhouse Gases
Primary ROE Question: What are the trends in outdoor air quality and effects on human health and ecological systems?

Question/Response

T1Q1 Are the physical, chemical, or biological measurements upon which this indicator is based widely accepted as scientifically and technically valid?

Summaries of methods and discussions of them can be found in: Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. at:

http://cdiac.esd.ornl.gov/trends/trends.htm Also, more detailed documentation of methods, uncertainties and some results can be found in the following references. For CO2: Barnola, J.-M., D. Raynaud, A. Neftel, and H. Oeschger. 1983. Comparison of CO2 measurements by two laboratories on air from bubbles in polar ice. Nature 303:410-13. Bacastow, R.B., C.D. Keeling, and T.P. Whorf. 1985. Seasonal amplitude increase in atmospheric CO2 concentration at Mauna Loa, Hawaii, 1959-1982. Journal of Geophysical Research 90(D6):10529-40. Etheridge, D.M., and C.W. Wookey. 1989. Ice core drilling at a high accumulation area of Law Dome, Antarctica. 1987. In Ice Core Drilling, edited by C. Rado and D. Beaudoing, pp. 86-96. Proceedings of the Third International Workshop on Ice Core Drilling Technology, Grenoble, France, October 10-14, 1988, CNRS, Grenoble. Etheridge, D.M., L.P. Steele, R.L. Langenfelds, R.J. Francey, J.-M. Barnola, and V.I. Morgan. 1996. Natural and anthropogenic changes in atmospheric CO2 over the last 1000 years from air in Antarctic ice and firn. Journal of Geophysical Research 101:4115-4128. Friedli, H., H. Lötscher, H. Oeschger, U. Siegenthaler, and B. Stauffer. 1986. Ice core record of 13C/12C ratio of atmospheric CO2 in the past two centuries. Nature 324:237-38. Guenther, P.R., A. Bollenbacher, C.D. Keeling, and D. Moss. 2002 Technical Report: Infrared Analyses of NOAA Primary CO2-in-Air Reference Gas Standards at SIO, 1991-1999. Guenther, P.R., G. Emanuele, and C.D. Keeling. 2002. Alternative Formulation of 1985-1999 Calibrations after Re-calibration of 4cc Chanber Volume of Mercury Manometer. Addendium to: Scripps Reference Gas Calibration System for Carbon-Dioxide-in Nitrogen and Carbon Dioxide-in-Air Standards: Revision of 1999, February 2002. See Diagram of the constant-volume mercury-column manometer. Herbert, G.A., E.R. Green, J.M. Harris, G.L. Koenig, S.J. Roughton, and K.W. Thaut, Control and monitoring instrumentation for the continuous measurement of atmospheric CO2 and meteorological variables, J. Atmos. Oceanic Technol., 3, 414-421, 1986. Keeling, C.D., R.B. Bacastow, and T.P. Whorf. 1982. Measurements of the concentration of carbon dioxide at Mauna Loa Observatory, Hawaii. In W.C. Clark (ed.), Carbon Dioxide Review: 1982. Oxford University Press, New York. Keeling, C.D., P.R. Guenther, G. Emanuele III, A. Bollenbacher, and D.J. Moss. 2002. Scripps Reference Gas Calibration System for Carbon Dioxide-in-Nitrogen and Carbon Dioxide-in-Air Standards: Revision of 1999 (with Addendum). SIO Reference Series No. 01-11. Lorius, C., J. Jouzel, C. Ritz, L. Merlivat, N.I. Barkov, Y.S. Korotkevich, and V.M. Kotlyakov. 1985. A 150,000-year climatic record from Antarctic ice. Nature 316:591-96. Morgan, V.I., C.W. Wookey, J. Li, T.D. van Ommen, W. Skinner, and M.F. Fitzpatrick. 1997. Site information and initial results from deep ice drilling on Law Dome. J. Glaciol. 43:3-10. Neftel, A., H. Oeschger, J. Schwander, B. Stauffer, and R. Zumbrunn. 1982. Ice core measurements give atmospheric CO2 content during the past 40,000 yr. Nature 295:220-23. Neftel, A., E. Moor, H. Oeschger, and B. Stauffer. 1985. Evidence from polar ice cores for the increase in atmospheric CO2 in the past two centuries. Nature 315:45-47. Petit, J.R., I. Basile, A. Leruyuet, D. Raynaud, C. Lorius, J. Jouzel, M. Stievenard, V.Y. Lipenkov, N.I. Barkov, B.B. Kudryashov, M. Davis, E. Saltzman, and V. Kotlyakov. 1997. Four climate cycles in Vostok ice core. Nature 387: 359-360. Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.-M. Barnola, I. Basile, M. Benders, J. Chappellaz, M. Davis, G. Delayque, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Li

T1Q2 Is the sampling design and/or monitoring plan used to collect the data over time and space based on sound scientific principles?

Most of the greenhouse gases presented in this indicator are considered to be well-mixed in the global atmosphere, due in large part to their long residence time in the atmosphere. Relatively small variations across different locations do occur, and hence the value in monitoring the concentrations at multiple locations, as in these indicator figures.

T1Q3 Is the conceptual model used to transform these measurements into an indicator widely accepted as a scientifically sound representation of the phenomenon it indicates?

Yes. See the references provided above.

T2Q1 To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question in the ROE?

The sampling and monitoring design is very appropriate for answering the relevant indicator for the gases covered, because these gases are relatively evenly distributed globally.

T2Q2 To what extent does the sampling design represent sensitive populations or ecosystems?

The sampling design does not represent sensitive populations or ecosystems in particular. However, the global measurements should be adequate for understanding the impacts on such populations or ecosystems, if such were identified.

T2Q3 Are there established reference points, thresholds or ranges of values for this indicator that unambiguously reflect the state of the environment?

No. Reference points are typically given as the mean over some period of measurement. Sometimes, a benchmark used is around 1850, to represent the atmosphere and climate system before significant anthropogenic influence is hypothesized to have occurred globally or regionally. No specific thresholds for damage have been scientifically established.

T3Q1 What documentation clearly and completely describes the underlying sampling and analytical procedures used?

Summaries of methods and discussions of them can be found in: Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. at: http://cdiac.esd.ornl.gov/trends/trends.htm Also, more detailed documentation of methods, uncertainties and some results can be found in the following references. For CO2: Barnola, J.-M., D. Raynaud, A. Neftel, and H. Oeschger. 1983. Comparison of CO2 measurements by two laboratories on air from bubbles in polar ice. Nature 303:410-13. Bacastow, R.B., C.D. Keeling, and T.P. Whorf. 1985. Seasonal amplitude increase in

atmospheric CO2 concentration at Mauna Loa, Hawaii, 1959-1982. Journal of Geophysical Research 90(D6):10529-40. Etheridge, D.M., and C.W. Wookey. 1989. Ice core drilling at a high accumulation area of Law Dome, Antarctica. 1987. In Ice Core Drilling, edited by C. Rado and D. Beaudoing, pp. 86-96. Proceedings of the Third International Workshop on Ice Core Drilling Technology, Grenoble, France, October 10-14, 1988, CNRS, Grenoble. Etheridge, D.M., L.P. Steele, R.L. Langenfelds, R.J. Francey, J.-M. Barnola, and V.I. Morgan. 1996. Natural and anthropogenic changes in atmospheric CO2 over the last 1000 years from air in Antarctic ice and firn. Journal of Geophysical Research 101:4115-4128. Friedli, H., H. Lötscher, H. Oeschger, U. Siegenthaler, and B. Stauffer. 1986. Ice core record of 13C/12C ratio of atmospheric CO2 in the past two centuries. Nature 324:237-38. Guenther, P.R., A. Bollenbacher, C.D. Keeling, and D. Moss. 2002 Technical Report: Infrared Analyses of NOAA Primary CO2-in-Air Reference Gas Standards at SIO, 1991-1999. Guenther, P.R., G. Emanuele, and C.D. Keeling. 2002. Alternative Formulation of 1985-1999 Calibrations after Re-calibration of 4cc Chanber Volume of Mercury Manometer. Addendium to: Scripps Reference Gas Calibration System for Carbon-Dioxide-in Nitrogen and Carbon Dioxide-in-Air Standards: Revision of 1999, February 2002. See Diagram of the constant-volume mercury-column manometer. Herbert, G.A., E.R. Green, J.M. Harris, G.L. Koenig, S.J. Roughton, and K.W. Thaut, Control and monitoring instrumentation for the continuous measurement of atmospheric CO2 and meteorological variables, J. Atmos. Oceanic Technol., 3, 414-421, 1986. Keeling, C.D., R.B. Bacastow, and T.P. Whorf. 1982. Measurements of the concentration of carbon dioxide at Mauna Loa Observatory, Hawaii. In W.C. Clark (ed.), Carbon Dioxide Review: 1982. Oxford University Press, New York. Keeling, C.D., P.R. Guenther, G. Emanuele III, A. Bollenbacher, and D.J. Moss. 2002. Scripps Reference Gas Calibration System for Carbon Dioxide-in-Nitrogen and Carbon Dioxide-in-Air Standards: Revision of 1999 (with Addendum). SIO Reference Series No. 01-11. Lorius, C., J. Jouzel, C. Ritz, L. Merlivat, N.I. Barkov, Y.S. Korotkevich, and V.M. Kotlyakov. 1985. A 150,000-year climatic record from Antarctic ice. Nature 316:591-96. Morgan, V.I., C.W. Wookey, J. Li, T.D. van Ommen, W. Skinner, and M.F. Fitzpatrick. 1997. Site information and initial results from deep ice drilling on Law Dome. J. Glaciol. 43:3-10. Neftel, A., H. Oeschger, J. Schwander, B. Stauffer, and R. Zumbrunn. 1982. Ice core measurements give atmospheric CO2 content during the past 40,000 yr. Nature 295:220-23. Neftel, A., E. Moor, H. Oeschger, and B. Stauffer. 1985. Evidence from polar ice cores for the increase in atmospheric CO2 in the past two centuries. Nature 315:45-47. Petit, J.R., I. Basile, A. Leruyuet, D. Raynaud, C. Lorius, J. Jouzel, M. Stievenard, V.Y. Lipenkov, N.I. Barkov, B.B. Kudryashov, M. Davis, E. Saltzman, and V. Kotlyakov. 1997. Four climate cycles in Vostok ice core. Nature 387: 359-360. Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.-M. Barnola, I. Basile, M. Benders, J. Chappellaz, M. Davis, G. Delayque, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Lipe

T3Q2 Is the complete data set accessible, including metadata, data-dictionaries and embedded definitions or are there confidentiality issues that may limit accessibility to the complete data set?

Yes. Among other locations, the data sets can be accessed over the internet with appropriate summaries, metadata and graphics, at: http://cdiac.esd.ornl.gov/trends/trends.htm There are no known confidentiality issues.

T3Q3 Are the descriptions of the study or survey design clear, complete and sufficient to enable the study or survey to be reproduced?

Yes. See references above. Also, there is a large degree of replication of findings across different studies.

T3Q4 To what extent are the procedures for quality assurance and quality control of the data documented and accessible?

They are accessible. See references provided above.

T4Q1 Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)?

Yes. Because the gases covered by this indicator have long residence times in the atmosphere, they are considered to be well-mixed. Although there are minor variations from sampling location to location, the overwhelming consistency among sampling locations indicates that extrapolation from these locations to the global atmosphere is reliable.

T4Q2 Are uncertainty measurements or estimates available for the indicator and/or the underlying data set?

Yes. See the references provided.

T4Q3 Do the uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?

Uncertainty does not impact the conclusions, and variability is represented in the data.

T4Q4 Are there limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or time period for which data are available?

The limitations of this indicator are minimal. There is relatively little scientific controversy over the magnitude of growth of atmospheric concentrations of CO2, CH4 or N2O during the Industrial Period. Moreover, the estimated concentrations from ice core data have been replicated and corroborated from a growing number of sites. The contemporary data are based on direct sampling, The record of direct sampling of CO2 concentrations (at Mauna Loa, Hawaii and at the South Pole) since 1957 is one of the longest and most consistent time series that atmospheric science has produced. Because all three gases are relatively well mixed globally over the time scales of concern, spatial

sampling error is a very small uncertainty. The overall trend of post-industrial increase in concentrations, and its magnitude relative to concentrations in the past 100 years, overwhelms the small local, daily, seasonal and inter-annual variability.